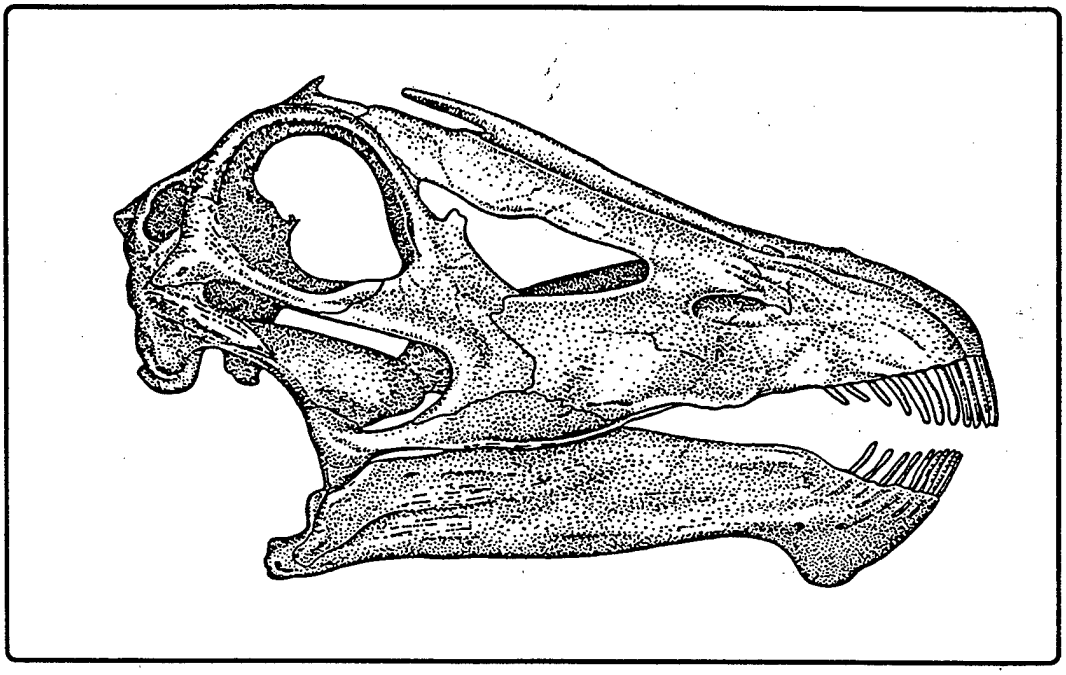
Results of the Field Study of the Surficial Geology and Paleontologic Resources of the Pinon Canyon Maneuver Site, Las Animas County, Colorado



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Prepared for and funded by
Department of the Army, Fort Carson Command,
The Directorate of Environmental Compliance and Management,
Fort Carson, Colorado

Report submitted to
Midwest Archeological Center
National Park Service
Lincoln, Nebraska

June 1998

RESULTS OF THE FIELD STUDY OF THE SURFICIAL GEOLOGY AND PALEONTOLOGIC RESOURCES OF THE PINON CANYON MANEUVER SITE, LAS ANIMAS COUNTY, COLORADO

By
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With Help From:
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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 1998	Final Report

4. TITLE AND SUBTITLE
Results of the Field Study of the Surficial Geology and Paleontologic Resources of the Pinon Canyon Maneuver Site, Las Animas County, Colorado

5. FUNDING NUMBERS

6. AUTHOR(S)
Emmett Evanoff

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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Boulder, CO 80309-0315

8. PERFORMING ORGANIZATION REPORT NUMBER
N/A

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Department of the Army, Fort Carson Command
Directorate of Environmental Compliance and Management
Fort Carson, CO 80913-5000

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
N/A

11. SUPPLEMENTARY NOTES
Prepared in cooperation with Midwest Archaeology Center, National Park Service, Federal Building, Room 474, 100 Centennial Mall North, Lincoln, Nebraska 685-3873

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Availability Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Pinon Canyon Maneuver Site contains a large number of fossils and fossil localities, ranging from dinosaur and plant beds to shell beds that were derived in an ancient sea. The lower sequences of sedimentary rocks that are exposed in the canyons along the Purgatoire River were deposited in wind, river, lake and shoreline environments. The upper sequence was deposited in a shallow seaway, the Western Interior Sea. The fossils of these marine rocks include clams, snails, and ammonoids that lived in the Gulf Coast region and in other continents. Pinon Canyon is one of the few places in the Western Interior Sea that these species of geographically widespread animals lived. The fossils of the lower canyons include fossil logs that accumulated as log jams the bottom of deep valleys. Nowhere else in the western United States are logs of this age known. Dinosaur bones, dinosaur stomach stones (gastroliths), and plant fossils occur in the Morrison Formation. The upper Dakota Group at the rims of the canyons contain abundant plant fossils, including some of the earliest fossils of flowering plants in the region.

14. SUBJECT TERMS
Paleontologic resources; dinosaur fossils, fossil logs, plant fossils, marine invertebrate fossils.

15. NUMBER OF PAGES
35

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

PREFACE

The paleontologic survey reported in this manuscript is an important part of the Fort Carson Cultural Resources Management Program whose goal is to maintain the largest possible area for military training while protecting significant cultural and environmental resources. The current study is a demonstration project funded by a grant awarded by the Legacy Resource Management Program. Legacy was established by Congress in 1991 to provide the Department of Defense (DoD) with an opportunity to enhance the management of resources on lands under DoD jurisdiction.

The Directorate of Environmental Compliance and Management (DECAM) is tasked with maintaining Fort Carson's compliance with federal, state and local environmental laws and mandates. The DECAM holistic management philosophy considers that all resources are interrelated such that decisions affection one resource will impact other resources. The decisions we make today will affect the condition of Department of Army lands and resources for future training, research and recreation. Mission requirements, training resources, wildlife, range, soil, hydrology, air, and recreation considerations all influence management decisions. Integrating compliance and resource protection concerns into a comprehensive planning process reduces the time and effort expended on the compliance process, minimizes conflicts between resource protection and use, allows flexibility in project design, minimizes costs, and maximizes resource protection.

Federal laws protect the resources on the Pinon Canyon Maneuver Site and Fort Carson; theft and vandalism are federal crimes. Protective measures ensure that Army activity does not inadvertently impact significant cultural and paleontologic sites. Fort Carson does not give out site location information nor are sites developed for public visitation. Similar resources are located in the Picketwire Canyonlands where public visits can be arranged through the U.S. Forest Service, Comanche National Grasslands in La Junta, Colorado.

Fort Carson endeavors to make results of the resource investigations available to the public and scientific communities. Technical reports on cultural resources are on file at the Fort Carson Curation Facility and Colorado State Historic Preservation Office and are available through the National Technical Information Service, Springfield, VA. Selected reports have been distributed to public libraries in Colorado. Three video programs produced by Fort Carson are periodically shown on Public Broadcasting Stations. Fort Carson continues to demonstrate that military training and resource protection are mutually compatible goals.

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Cultural Resources Manager
Directorate of Environmental Compliance
and Management
Fort Carson, Colorado

April 1998

Acknowledgments

The field crew for this project included Benjamin Burger, Melissa Burke, Evan Hall, William Hughes, Alan Lester, Paul Murphey, Sandra Swift, and Kathryn Townsend. The competence and enthusiasm of the field crew was of great help and is greatly appreciated. Unpublished data on the thicknesses of the stratigraphic units in the canyons was provided by Dr. Fred Peterson of the U.S. Geological Survey. Mr. Paul Murphey drafted the final copies of the geologic maps on a map base of 1:24,000 scale.

Anne Vawser of the National Park Service has been the principal government contact for this project. Government contacts while in the field included Stephen Chomko from Fort Carson, and Dan Crouch and Melissa Connor from the National Park Service. I extend my appreciation to these personnel and others at the PCMS and the Midwest Archeological Center, Lincoln, Nebraska, for allowing this study to be made.

Funding for this project was provided by the Department of Defense Legacy Resource Management Program (Contract Number 1443PX6115970067).

Cover illustration is of the skull of *Diplodocus* from Ostrom and McIntosh (1966).

Technical Abstract

The sedimentary rock sequence in the canyons of the the Pinon Canyon Maneuver Site is composed of nine stratigraphic units, two of which have high paleonotologic significance. These two important units are the Bell Ranch and Morrison formations. The Bell Ranch Formation is a series of multicolored breccias, sandstones and siltstones that were deposited in a series of valleys cut into the underlying dune sands of the Entrada Formation. The Bell Ranch contains local accumulations of logs near the base of the deepest paleovalleys and these logs are unique for the Middle Jurassic record of the western United States. The name Bell Ranch for these rocks is an extension of the nomenclature from northeast New Mexico. The Morrison Formation contains a three part sequence including a lower gypsum and gray mudrock interval, a middle limestone and claystone interval, and an upper multicolored mudstone and sandstone interval. The lower interval is unfossiliferous, but the middle interval contains plants, invertebrates (ostracodes) and includes the dinosaur tracks of the adjacent Picketwire Track Site. The upper interval contains scattered accumlations of dinosaur bones, mostly of sauropods. Two localities, both in Welsh Canyon, have large accumulations of bones. Fossils occur in the Cretaceous Dakota Group that caps the rims of the canyons, but none of the fossils are unique for the region. The most fossiliferous unit in the Dakota is the Pajarito Formation, a sequence of alternating sandstones and carbonaceous shales with locally abundant plant fossils. One locality of dinosaur tracks occurs in the upper transition units of the uppermost Dakota. The names Pajarito and Mesa Rica Sandstone are extended to the rocks of the upper Dakota from equivalent units in New Mexico. The oldest two units in the canyons, the upper Dockum Group and the Entrada Sandstone, are unfossiliferous. The Entrada Sandstone is very thick in the canyons, contrary to what has been reported for the area.

Of the 12 fossil localities documented in this study, only four are considered to be of high paleontologic significance. These include the two petrified wood localities (96 Pal 3 and Jb OVM 1) in the Bell Ranch, and the two dinosaur bone localities (Jm OVM 1 and Jm OVM 4) in the Morrison of Welsh Canyon. These localities and the other dinosaur bone localities should be periodically monitored for new fossil materials and to determine the impact of human activities. Any plans for future construction in the area should consider any of the documented fossil localities of this study and of Kauffman (1986). Potential research projects derived from this study include 1) a study of the distribution and origin of the Bell Ranch Formation and its flora, 2) a detailed study of the sedimentology and stratigraphy of the Morrison Formation, 3) a taxonomic and paleoecologic study of the fossil plants of the Pajarito flora, and 4) additional field mapping of the Cretaceous marine rocks.

Popular Abstract

The Pinon Canyon Maneuver Site contains a large number of fossils and fossil localities, ranging from dinosaur and plant beds to shell beds that were derived in an ancient sea. The lower sequence of sedimentary rocks that are exposed in the canyons along the Purgatoire River were deposited in wind, river, lake, and shoreline environments. The upper sequence was deposited in a shallow seaway, the Western Interior Sea. The fossils of these marine rocks include clams, snails, and ammonoids (extinct squid-like animals with hard external shells) that lived in the Gulf Coast region and in other continents such as Africa and Europe. Pinon Canyon is one of the few places in the Western Interior Seaway that these species of geographically widespread animals lived. The fossils of the lower canyons include fossil logs that accumulated as log jams at the base of deep valleys. Nowhere else in the western United States are logs of this age known. The most important unit for dinosaurs in the area is the Morrison Formation, for it contains dinosaur bones and dinosaur stomach stones (gastroliths). the Picketwire Track Site just to the east of the Pinon Canyon Maneuver Site is within the Morrison Formation. Plant fossils also occur in the Morrison, but plant fossils are more abundant in the uppermost rocks that support the rims of the canyons (the upper Dakota Group). These plants include some of the earliest fossils of flowering plants known from the region. At least one dinosaur trackway occurs in the rocks just above those containing the plants, near the top of the Dakota Group.

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RESULTS OF THE FIELD STUDY OF THE SURFICIAL GEOLOGY AND PALEONTOLOGIC RESOURCES OF THE PINON CANYON MANEUVER SITE, LAS ANIMAS COUNTY, COLORADO

Emmett Evanoff

The Pinon Canyon Maneuver Site (PCMS) in Las Animas County, Colorado (Figure 1) contains a 400 m sequence of sedimentary rocks, some of which contain abundant fossils. These fossils include a wide variety of vertebrate, invertebrate, plant, and trace fossils. The purpose of this report is to: 1) document the known occurrences of fossils in the lower portion of these rocks as derived from field studies and 2) to amend the surficial geology and paleontologic resources maps of the PCMS (Evanoff 1997). This work represents the results of a field evaluation of the geology and fossil resources of a part of the area not examined extensively by a previous paleontological survey (Kauffman 1986). Specifically, the rocks examined were those exposed in the canyons in the eastern part of the area. This work will help land managers of the PCMS to manage the paleontologic resources.

Previous geologic maps of part or all of the PCMS include those of Stose (1912), Duce (1924), Gould (1934), Bass et al. (1947), Maher and Collins (1953), Scott (1968), Johnson (1969), Taylor (1974), and Kauffman (1986). The stratigraphy of the rocks have been documented by Lee (1901), Stose (1912), Duce (1924), Keyes (1940), Maher (1946), Oriel and Mudge (1956), Long (1966), Cobban (1968), Cobban and Scott (1972), Taylor (1974, 1980), Kauffman (1986), and Mateer (1987). The paleontology of the PCMS has been documented by Cobban (1971), Cobban and Scott (1972), Taylor (1974), and Kauffman (1986). Geomorphological and geoarcheological investigations of the area have been reported by Schuldenrein (1985), and the geoarcheology of the PCMS has been reported by McFaul and Reider (1990).

Methods

This project included examining the outcrops of the eastern canyons to determine the paleontologic resources and to check the validity of the previous mapping provided by Evanoff (1997). Rocks of all the major canyons on the eastern part of the PCMS were examined including Taylor Arroyo, Spring Canyon, Lockwood Arroyo, Red Rock Canyon, Welsh Canyon, Bravo Canyon, Bent Canyon, Sugarloaf Canyon, Horse Canyon, Stage Canyon, Iron Canyon, Minnie Canyon, and all the smaller unnamed canyons adjacent to and within these larger canyons (Figure 1). The rocks examined included the oldest rock units in the area, determined to be of the Triassic upper Dockum Group, to the uppermost sandstones of the Cretaceous Dakota Group. The younger marine rocks of the central and western parts of the area were not examined, except to clarify the stratigraphy

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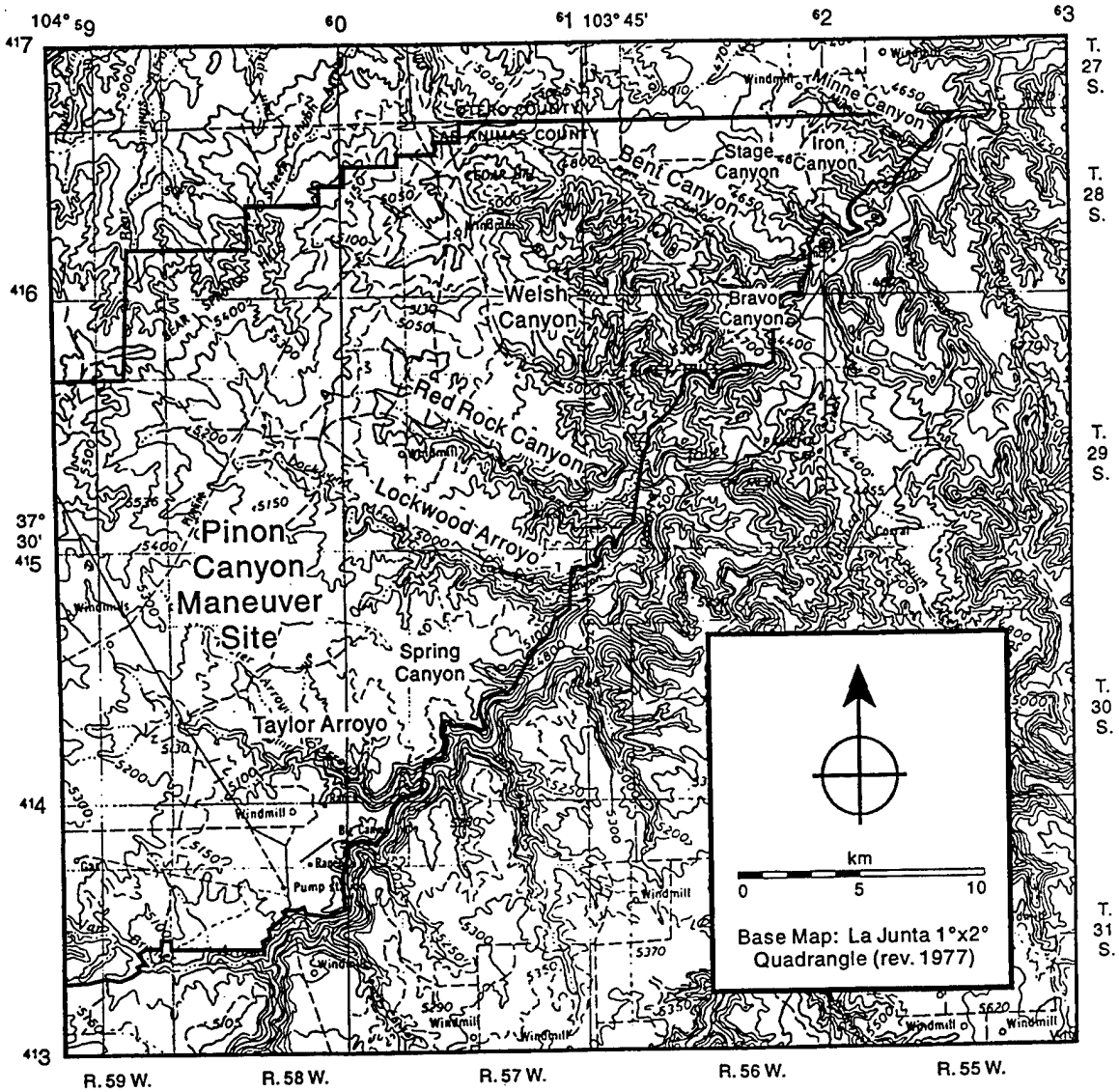

Figure 1. Map of the eastern half of the Pinon Canyon Maneuver Site showing the distribution of canyons and arroyos west of the Purgatoire River examined during this project. UTM Zone 13; Public Land Survey 6th Principal Meridian.

(such as the presence of the Smoky Hill Member of the Niobrara Formation) and relocate problematic localities given by Kauffman (such as Kauffman's Greenhorn locality #22). Kauffman's (1986) paleontological survey was quite comprehensive concerning the marine faunas in the rocks above the Dakota Group, but questions remained concerning the distribution and amount of fossils in the lower, primarily terrestrial, sequence.

The fieldwork that is compiled in this report was performed on 30 May to 12 June and 2-9 July 1997. The field crew divided into groups of two to three workers that hiked the canyons examining the rock outcrops for fossils and making notes on the distribution of rock exposures and fossil localities. Small representative collections from the important localities were made for helping future researchers recognize the fossil resources. Subsequent work in the office has included sorting and labeling the collections, revising the maps using the field data to more accurately represent the geology of the eastern canyons, and to plot the new fossil localities on the maps to add to the previous paleontologic resources data base. The revised mapping includes parts of the following 7½ quadrangle maps: Beaty Canyon (1972, rev. 1984), Doss Canyon North (1972, rev. 1984), Johnson Canyon (1972, rev. 1984), OV Mesa (1993), Packers Gap (1993), Riley Canyon (1993), Rock Crossing (1993), Sheep Canyon (1993), and Stage Canyon (1993).

Stratigraphy

Nine major Mesozoic sedimentary units, one Tertiary shallow intrusive unit, and five mappable Quaternary deposits occur in the PCMS (Figure 2). These units are described in Table 1. The nomenclature used is a composite of those used by Scott (1968), Johnson (1969), Taylor (1974), and Kauffman (1986) with a few new additions. A history of the nomenclature is shown in Figure 3. The current study has emphasized the geology and paleontology of the eastern canyons of the PCMS and the detailed stratigraphy of these canyons is presented in Figure 4.

The oldest rocks exposed in the PCMS are those of the upper part of the Triassic Dockum Group. These fine-grained, horizontally bedded red sandstones occur in the lower part of Bravo Canyon (Figure 5) in the center of the E½, section 34, T. 28 S., R. 56 W. The Entrada Sandstone is much thicker than what has been previously stated in the literature (88 m thick, relative to the 4 m thick reported in Evanoff 1997) and supports massive cliffs in the lower canyons (Figure 6). Previous workers confused most of the Entrada Sandstone with sandstones of the upper Dockum Group, a problem first recognized by Fred Peterson (written communication, May, 1997). The Entrada is truncated by a paleovalley system that was filled with breccia and sandstones of the Bell Ranch Formation (Figure 7). The Bell Ranch is a Middle Jurassic unit that occurs between the Entrada and Morrison formations in northeast New Mexico (Griggs and Read 1959; Lucas, Hunt and Kues 1987). Previous workers have placed these sandstones and the overlying gypsum beds into the Ralston Creek Formation (see Taylor 1972), but recent regional stratigraphic studies indicates that the Ralston Creek to be the lower beds of the Morrison Formation, and the underlying variegated sandstones and mudstones are separated from the gypsum beds by a major unconformity (Fred Peterson, written communication, May 1997). The name Ralston Creek Formation is not used herein for

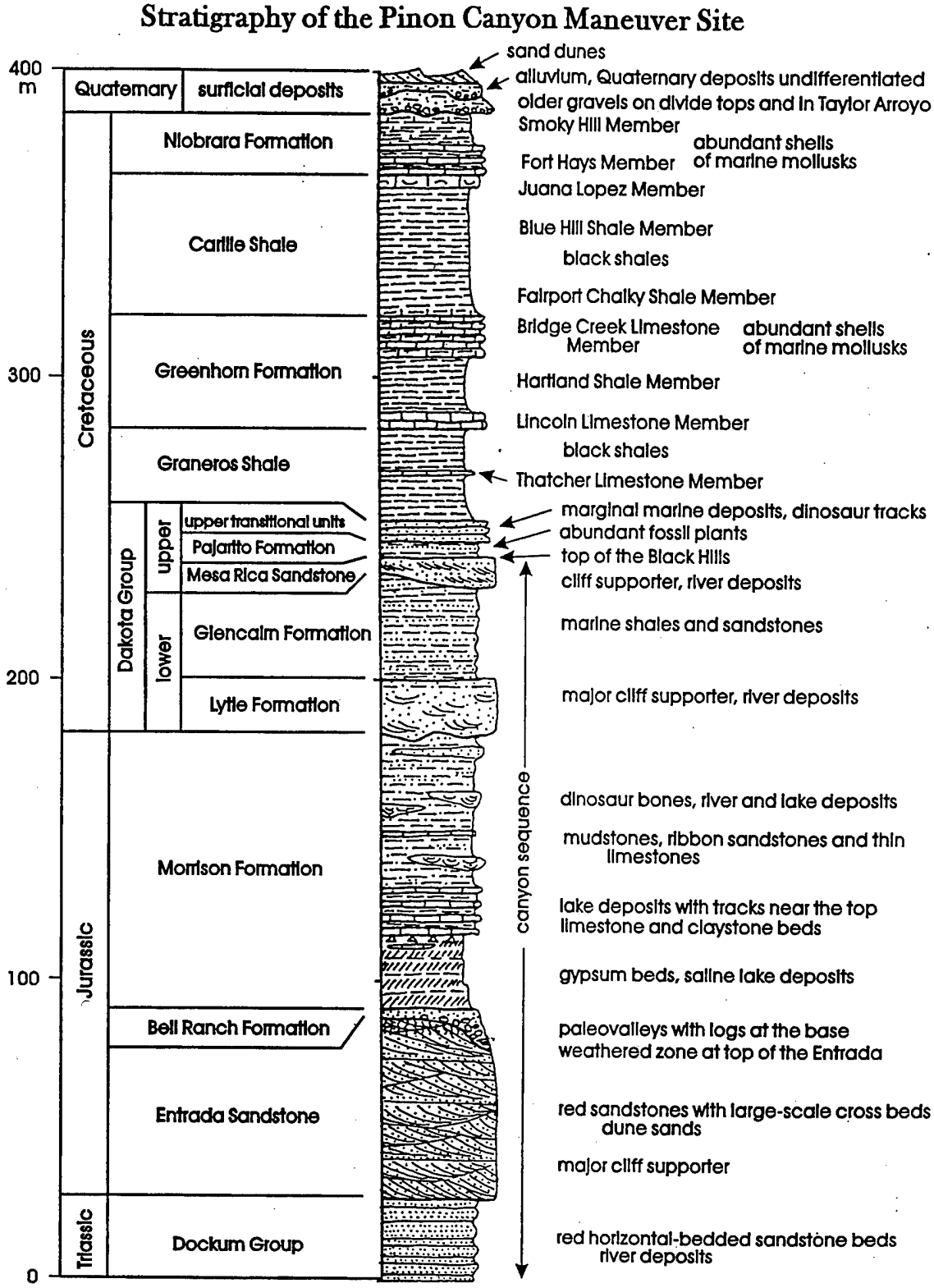

Figure 2. Stratigraphic column of the sedimentary rock units exposed in the Pinon Canyon Maneuver Site. Thickness are from Kauffman (1986) and Peterson (written communication, May 1997).

TABLE 1. LITHOSTRATIGRAPHIC UNITS IN THE PINON CANYON MANEUVER SITE.

Qa **Modern alluvium.** Holocene. Primarily clayey silt and sand along modern drainages. Can locally contain shells of freshwater clams and snails and land snails. Low to moderate fossil potential.

Qls **Landslide deposits.** Upper Quaternary. Poorly sorted deposits in debris slides and earthflows, primarily below Dakota Sandstone and along terrace scarps. Low fossil potential.

Qsd **Sand dunes.** Upper Quaternary. Yellowish gray sand occurring in longitudinal dunes on the western slopes of the area. Low fossil potential.

Qog **Older gravels.** Lower Quaternary and Pliocene? Gravels on high terrace near the mouth of Taylor Arroyo, containing gneiss, chert, and basalt cobbles. Low fossil potential.

Qu **Upper Quaternary Sediments Undifferentiated.** Deposits that include older alluvium, slopewash and colluvium in valley bottoms and on slopes. Includes the "Pitty gravels" of Helgren et al. (1985) on divides above the canyons of the Purgatoire River. Low to moderate fossil potential.

Ti **Intrusive rocks.** Oligocene. Dark-gray finely crystalline dikes of olivine basalt that supports ridges in the southwest margin of the area. No fossil potential.

Niobrara Formation. Upper Cretaceous. Abundant light colored limestones with interbedded shales. Moderate fossil potential; abundant invertebrate fossils and rare vertebrate fossils. 225 m, 737 ft. thick.

Kns **Smoky Hill Member.** Calcareous shale and ledge forming limestone with interbedded chalk. Lower portion includes abundant limestone beds; while upper portion is dark calcareous shales. Limited outcrops occur by the western-most boundary of the area.

Knf **Fort Hays Member.** Fine grained micritic limestone separated by thin beds of soft calcareous shale. Limestone is olive-gray to white and weathers to buff. Shales are well laminated, olive-gray and weathers to yellowish-gray. 10 m, 33 ft, thick.

Kc **Carlile Shale.** Upper Cretaceous. Darker colored sands and shales with lenses of calcarenite. Moderate fossil potential; abundant invertebrate fossils and rare vertebrate fossils. 46 m, 152 ft, thick.

Juana Lopez Member. Lenses of dark brownish-gray fine-grained well laminated calcarenite containing patches of light gray glauconite. Contains abundant marine fossils. 3 m, 11 ft, thick

Blue Hill Shale Member. Dark-gray soft to well indurated well laminated shale. Upper half is sandy and contains two prominent layers of septarian limestone concretions. 28 m, 91 ft, thick.

Fairport Chalky Member. Dark olive-gray to black, well laminated soft calcareous shale. Yellowish-gray limestone near base. 16 m, 51 ft, thick.

Kgh **Greenhorn Formation.** Upper Cretaceous. Calcarenite limestone beds with dark gray platy to fissile shale beds. Moderate fossil potential with abundant invertebrate fossils and rare vertebrate fossils. 37 m, 121 ft. thick.

Bridge Creek Limestone Member. Gray, shaly weathering micritic limestone beds separated by soft calcareous shale and bentonite layers. 13 m, 43 ft, thick.

Hartland Shale Member. Dark gray calcareous platy shale and thin layers of calcarenite composed of tests of foraminifera and prisms of *Inoceramus* shells. 18 m, 60 ft, thick.

Lincoln Limestone Member. Layers of dark gray, platy, shaly calcarenite composed of tests of foraminifera and prisms of *Inoceramus* shells; separated by dark gray soft calcareous shale. 5.6 m, 18 ft, thick

Kg **Graneros Shale.** Upper Cretaceous. Dark gray fissile, soft to medium-hard, non-calcareous shale and numerous bentonitic beds. Ferruginous siltstone contains fish scale and bones.. Moderate fossil potential with abundant invertebrates and rare vertebrates. 30 m, 98 ft, thick.

Thatcher Limestone Member. Bench-forming micritic limestone separating the upper and lower black shales. Diverse mollusk fossils. 0.2 m, 0.5 ft, thick.

Kd **Dakota Group.** Lower Cretaceous. Fine to course-grained sandstones and conglomerates with interbedded claystone, shales and siltstones. Upper contact is conformable, the base is unconformable. Trace fossils are abundant and plant fossils (wood, stems, and leaves) are locally numerous at the top. Dinosaur tracks are rare, but are present in the upper-most sandstone beds. Can be divided into a lower and upper interval, with the Lytle and Glencairn formations in the lower part, and the Mesa Rica, Pajarito, and upper transition units comprising the upper part. The upper part has a moderate fossil significance for abundant fossil plants and rare dinosaur tracks. 71 m, 231 ft, thick.

upper transition units. Platy to massive brown fine-grained sandstones with abundant trace fossils and symmetric ripplemarks. Locally has a thick basal sandstone filling scours in the underlying Pajarito Formation. Contains rare dinosaur tracks. 7m, 23 ft, thick.

Pajarito Formation. Alternating flaggy brown to white sandstones and gray to brown muddy shales. The shales are typically carbonaceous and locally have fossil leaves. The sandstones are rippled, highly burrowed and contain numerous wood impressions. The fossil wood is typically burrowed by shipworms (*Teredo*). 4.5 m, 15 ft thick.

Mesa Rica Sandstone. A cliff-forming quartz-rich cross-bedded sandstone. The sandstones are medium to fine grained and are white to yellow brown that typically weather rusty brown. Many highlands, such as the Black Hills, are capped by this unit. Fossils are rare in these sandstones. 6 to 9 m, 19 to 30 ft, thick

Glencairn Formation. Black to dark gray, fissile basal shale grading upwards into interbedded tan siltstones and sandstones. Contains rare shells of marine clams, abundant trace fossils, and shale beds containing numerous fish scales. 33 to 36 m, 107 to 117 ft, thick.

Lytle Formation. Coarse to fine-grained white sandstones with alternating mudstone layers towards the top. Capped by a thin interval of conglomeratic, brown-weathering resistant sandstones, called the Plainview by several researchers. The Lytle supports large cliffs in the area. Lytle fossils are rare in the area and are limited to scattered casts of logs. 17 to 29 m, 57 to 95 ft, thick.

Jm **Morrison Formation.** Upper Jurassic. Consists primarily of mudrocks (claystones and mudstones) alternating with thick gypsum beds, thin limestones and sandstone sheets and ribbons. Colors range from white, light grays, blues and green at the base to reds, purples and yellows at the top. Fossil potential is high. Formation strata have yielded fossil plants, dinosaur tracks and bones from the area. Total thickness: 92 m, 302 ft, thick. The Morrison can be divided into three parts:

upper Morrison. Composed predominantly of multicolored mudstones and claystones, with interbedded gray to brown sheet and ribbon sandstones, and thin widespread brown to gray limestones that weather to a rusty brown. Swelling clays (smectites) are abundant in the mudrocks and act as slip surfaces for numerous landslides that typically cover the upper Morrison outcrops. Fossils include dinosaur bones, typically in conglomeratic sandstones and rarely in the mudrocks, and scattered gastroliths. 51 m, 167 ft, thick.

middle Morrison. Alternating white micritic limestones and greenish gray claystones. The limestones have algal laminations (stromatolitic) in the lower part. Fossil ostracodes and

silicified plant fragments occur in the upper limestones. The Picketwire track site is in the upper-most limestones of this interval. 16 m, 52 ft, thick.

lower Morrison. Alternating thick gypsum beds and gray mudrocks, mostly claystones and mudstones, with thin sandstone partings. The gypsum beds are easily eroded and this interval is poorly exposed in a flat bench on top of the Bell Ranch. The top of this interval is marked by a widespread interval of bluish gray to red welded chert locally forming thick masses. No fossils are known from this interval. 25 m, 83 ft, thick.

Jb **Bell Ranch Formation.** Middle Jurassic. Lower part is composed of multicolored sandstones and breccias filling deep paleovalleys. Colors in the lower part range from dark red-brown, purple, brown-orange to green-gray. Upper part is composed predominantly of red to purple siltstones and sandstones. Large silicified logs, up to 1.45 m (4.8 ft) in diameter, are locally present in the deepest part of the paleovalleys. Rare vertebrates are reported from the upper beds. The unit's fossil significance is high. Thickness varies greatly from near 0 m thick to 14 m, 44 ft, thick.

Je **Entrada Sandstone.** Middle Jurassic. Massive, salmon-red, to white, well sorted, fine-grained sandstone. Highly bedded in large to very large crossbed sets. Upper part has a well-developed weathering zone. The Entrada is a prominent cliff supporter in the lower canyons. No fossils are known from the unit in the area. 88 m, 288 ft thick.

TRd **Dockum Group.** Triassic. Coarse- to very fine-grained red sandstone with thick to thin horizontal bedding. Boulder conglomerate and chert beds near top. Fossilized plant material, invertebrates, and vertebrates known from other areas, but no fossils are known from the area. 28 m, 98 ft thick.

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the rocks in the PCMS. The Morrison Formation includes a lower gypsum sequence, a middle limestone and green claystone sequence (Figure 8), and an upper variegated mudstone and sandstone sequence (Figure 9).

The nomenclature of the Dakota Group is problematic (Figure 10). The Dakota can be divided into two major divisions, a lower part composed of the Lytle and Glencairn formations, and an upper part that includes a basal sandstone, a middle shale, and an upper sandstone interval. In the field the two subdivisions are marked by the base of the upper sandstone cliffs in the canyons (Figure 11). Early workers named these divisions the Purgatoire Formation and the Dakota Sandstone. Subsequent workers (Kauffman 1986; Mateer 1987) have included all of these units in the Dakota Group and named the upper division the Muddy Formation, a name given to correlative rocks in north-central Wyoming. Workers of the Cretaceous rocks of northeast New Mexico have named the individual units in the upper Dakota and some of these names have herein been extended into the study area. These include the Mesa Rica Sandstone for the lower sandstone interval, and the Pajarito Formation for the middle shale sequence. The name Romeroville Sandstone has not been extended into the area, for the upper sandstone interval includes two units that may not be equivalent to the Romeroville. The lower and upper parts of the Dakota Group are distinct in the aerial photographs and have been mapped.

The Cretaceous rocks of marine origin overlying the Dakota have been discussed extensively in Kauffman (1986) and are summarized in Table 1. The units mapped in this study do not include the subdivisions of the Cretaceous rocks as indicated by Kauffman (1986), because the members of the Graneros, Greenhorn, and Carlile formations are not

Age	Scott, 1968, & Taylor, 1974			Kauffman et. al., 1986			Evanoff, 1997		This Report			Map Symbol
Cretaceous	Niobrara Formation	Smoky Hill Member		Niobrara Formation	Fort Hays Member		Niobrara Formation	Smoky Hill Member	Niobrara Formation	Smoky Hill Member		Kns
		Fort Hays Member						Fort Hays Member		Fort Hays Member		Knf
	Carlile Shale			Carlile Shale	Juana Lopez Member		Carlile Shale		Carlile Shale			Kc
					Blue Hill Shale Member							
					Fairport Member							
	Greenhorn Limestone			Greenhorn Formation	Bridge Creek Ls Memb.		Greenhorn Limestone		Greenhorn Limestone			Kgh
					Hartland Shale Member							
					Lincoln Ls Member							
	Graneros Shale			Graneros Shale	upper shale		Graneros Shale		Graneros Shale			Kg
					Thatcher Ls Member							
					lower shale							
	Dakota Sandstone	upper sandstone		Dakota Group	Muddy Sandstone	upper sandstone	Dakota Group		Dakota Group	upper	upper transitional units	Kdu
		Dry Creek Canyon Member				Dry Creek Canyon Member					Pajarito Formation	
		lower sandstone				lower sandstone					Mesa Rica Sandstone	
	Purgatoire Formation	Glencairn Shale Member	upper shale		Glencairn Formation					lower	Glencairn Formation	Kdl
			middle shale									
			lower shale									
		Plainview Sandstone Member			Plainview Formation						Lytle Formation	
		Lytle Sandstone Member			Lytle Formation							
Jurassic	Morrison Formation			Morrison Formation			Morrison Formation		Morrison Formation			Jm
	Ralston Creek Formation			'middle unit'	upper gypsum & limestone member		Ralston Creek Formation		Bell Ranch Formation			Jeb
					lower sandstone m.							
	Entrada Sandstone			Entrada Sandstone			Entrada Sandstone		Entrada Sandstone			
Triassic	Dockum Group						Dockum Group		Dockum Group			TRd
Permian	Big Basin Formation			Lykins Formation	Strain Shale Member		Big Basin Formation					Not in Area
	Day Creek Dolomite				Forelle Ls Member		Day Creek Dolomite					
	Whitehorse Sandstone						Whitehorse Sandstone					

Figure 3. A partial history of the stratigraphic nomenclature of the sedimentary rocks in the Pinon Canyon Maneuver Site.

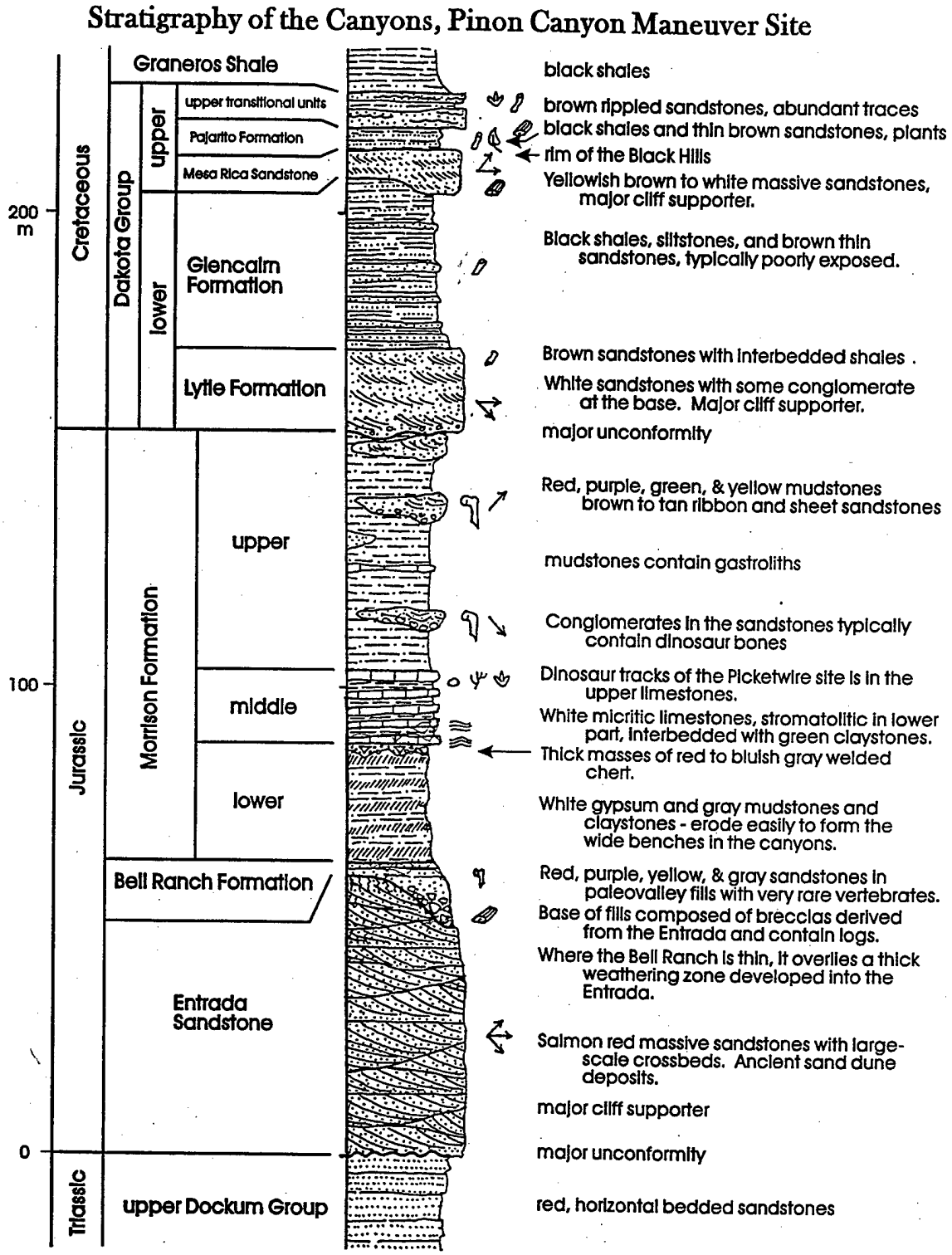

Figure 4. Stratigraphic column showing the sedimentary rock units exposed in the canyons of the eastern part of the Pinon Canyon Maneuver Site. The thicknesses are from Kauffman (1986) and Peterson (written communication, May 1997).

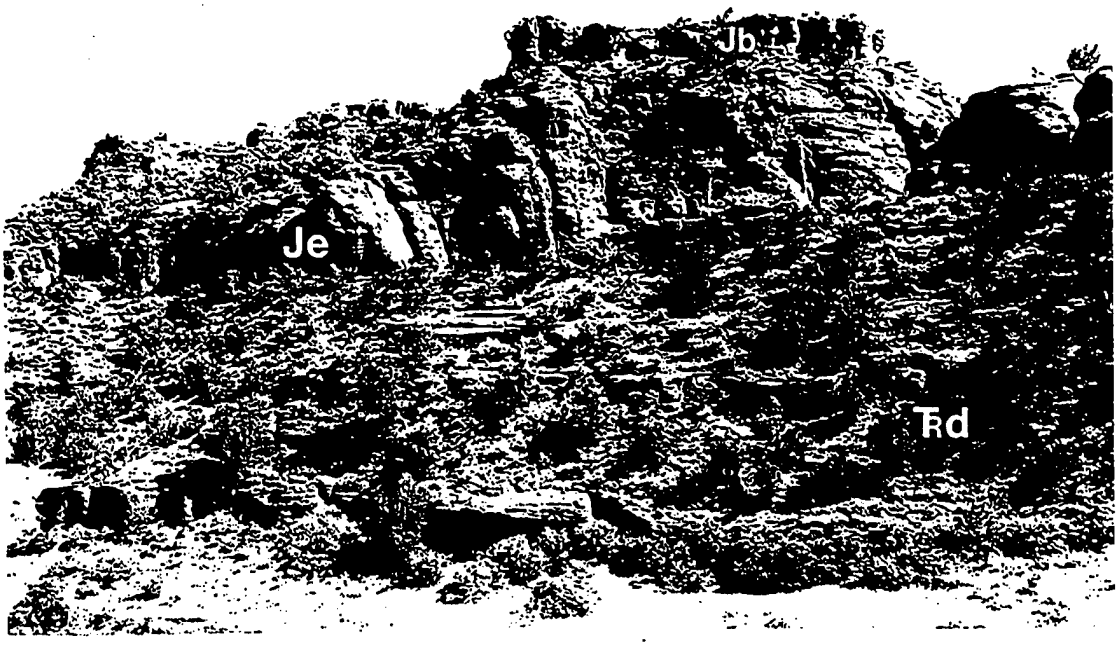

Figure 5. View of the horizontal bedded red sandstones of the upper Dockum Group (TRd) under the rounded massive cliffs of the Entrada Sandstone (Je). The red sandstones at the skyline are sandstones in the Bell Ranch Formation (Jb). The white bench below the Bell Ranch sandstones is the weathering zone on the top of the Entrada Sandstone. The view is to the southeast in the lower part of Bravo Canyon. Photograph provided by Paul Murphey.

Figure 6. Large massive cliffs of cross bedded sandstones of the upper Entrada Sandstone. The view is to the northwest near the mouth of Red Rock Canyon.

Figure 7. View to the northeast of the Bell Ranch conglomerates overlying bleached sandstones of the Entrada Sandstone. The view is a cross section through a paleovalley, with the contact between the two formations extending from the field assistant's hand to the upper right of the photograph. The location is up the valley from the Lost Korgel Forest, (96 Pal 3). Sandra Swift is the field assistant.

easily mapped off of the aerial photographs. Kauffman (1986) did not recognize the Smoky Hill Member of the Niobrara Formation in the area but these rocks are exposed near the western edge of the PCMS south of the Cantonment (in sections 5, 6, and 19, T. 30 S., R. 60 W.).

The Quaternary deposits of the area have been greatly generalized on the maps. Large areas are covered by a combination of older alluvium, pediment sediments, and colluvium that are not easily distinguished on the aerial photographs or on the ground. These deposits have been mapped as Quaternary undifferentiated sediments (Qu) on the maps. In addition, old lag gravels, informally named the "Pitty gravels" by Helgren et al. (1985) that occur on the tops of divides in the area have been included in these undifferentiated Quaternary sediments. Schuldenrein (1985) has determined that all of the unconsolidated sediments in the PCMS is probably Holocene (late Quaternary) in age, except for the "Pitty gravels" that may be lag gravels derived from the Miocene Ogallala Formation that once covered the region. However, older gravels also occur on a high terrace near the mouth of Taylor Arroyo. These gravels include clasts of gneiss, chert, and basalt, lithologies that are not found in the modern drainage basin of Taylor Arroyo. Quaternary debris derived from the Dakota Group covers much of the exposures of the fossiliferous upper Morrison in the canyons. In some cases these Morrison exposures are covered by Quaternary landslides that moved on the mudrocks with swelling clays in the upper Morrison. Only the largest of these landslides have been mapped.

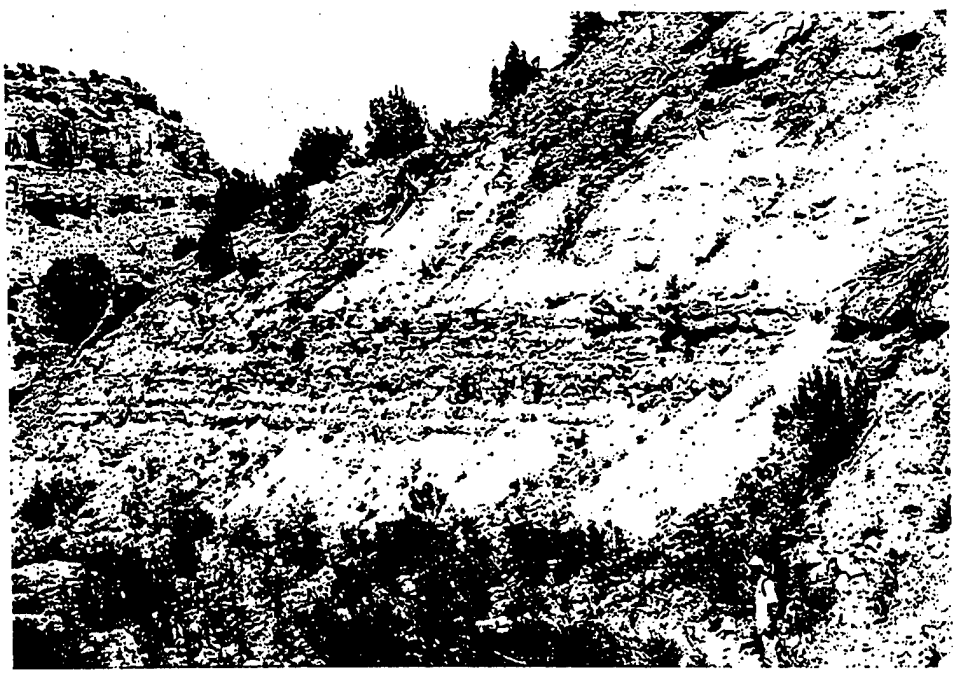

Figure 8. Alternating limestone and claystone beds of the middle Morrison Formation near the mouth of Taylor Canyon at Jm DCN 1. The view is to the east and the field assistant is William Hughes.

Figure 9. View to the southwest of the upper Morrison in Minnie Canyon. Included are variegated mudstones and a large sandstone ribbon (channel deposit) on the right. The cliff on the skyline is in the Dakota Group. This outcrop is in the SW¼, NE¼, SE¼, sec. 6, T. 28 S., R. 55 W

	Stose, 1912, & Finlay, 1916		Waage, 1953 E Colorado		Long, 1966 SE Colorado	Scott, 1968, & Taylor, 1974 SE Colorado		Mateer, 1987 SE Colorado		Kues & Lucas, 1987 NE New Mexico		This Report	
Dakota Group	Dakota Sandstone		Dakota Sandstone	upper sandstone unit	transitional unit	Dakota Sandstone	upper sandstone unit	Muddy Formation	upper transitional mem.	Dakota Group	Romeroville Sandstone	upper Dakota	upper transitional units
					upper sandstone member				upper sandstone mem.				
				Dry Creek Canyon Mem	Dry Creek Canyon Mem		Dry Creek Canyon Mem		Dry Creek Canyon Mem		Pajarito Formation		Pajarito Formation
				lower sandstone unit	lower sandstone member		lower sandstone unit		lower sandstone unit		Mesa Rica Sandstone		Mesa Rica Sandstone
	Purgatoire Fm.	Glencairn Shale	Purgatoire Fm.	Glencairn Shale	Glencairn Shale	Purgatoire Fm.	Glencairn Shale M. upper shale middle shale lower shale	Glencairn Formation		Glencairn Formation		lower Dakota	Glencairn Formation
					Basal Glencairn sandstone		Plainview Ss Memb.	Plainview Fm.			Long Canyon Sandstone Bed		Lytle Formation
		Lytle Sandstone		Lytle Sandstone	Lytle Sandstone		Lytle Sandstone Member	Lytle Formation		Lytle Sandstone			

Figure 10. A history of the stratigraphic nomenclature of the Dakota Group in southeast Colorado and northeast New Mexico.

Figure 11. The Dakota Group exposed in the north cliffs at the mouth of Taylor Arroyo. The lower cliff is supported by the Lytle Formation, the upper cliff are supported by the Mesa Rica Sandstone. The base of the Mesa Rica cliff marks the contact between the lower and upper Dakota. The view is looking toward the northeast from the top of the Mesa Rica cliff.

Paleontologic Resources

The paleontologic significance of a stratigraphic unit in any area depends on three criteria. The first criterion is the presence of rare taxa, the second is the diversity of the plant and animal fossils (biota), and the third is the abundance of fossils in a stratigraphic unit. Of these three criteria, the first one is the most important for fossils may be diverse and abundant in a rock unit but if the taxa are widespread and common in other areas then their significance is much reduced. Fossils abound in many of the stratigraphic units in the PCMS, but only a few of the units contain rare or unique taxa. Thus, only a few units are of high significance, though additional study may find additional taxa in the stratigraphic units that are now thought to be less significant paleontologically. Fossils are also typically clumped in their distribution, especially those that were deposited in terrestrial environments, so individual localities become significant or not, depending on the three criteria given above. Localities also become important if they are the source of new taxa - such localities become type localities for the newly described taxa. Finally, the traditional criteria for ranking includes an emphasis for vertebrate fossils. Vertebrate fossils tend to be much more rare than invertebrate, plant, or trace fossils, and are considered to be more significant by most researchers. However, the most significant fossils described in this report, the Middle Jurassic logs of the Bell Ranch Formation, reflect their unique occurrence in the rock sequence of the western United States.

Invertebrate, plant, and trace fossils are all locally very abundant in the PCMS (Table 2). Vertebrate fossils are less common, but are important constituents of only one stratigraphic unit, the upper Morrison Formation. Units that have produced rare invertebrates or include type localities for fossil invertebrate species include the Thatcher Limestone Member of the Graneros Shale, the limestone units of the Greenhorn Formation, and the Fort Hays Member of the Niobrara Formation. The individual localities for these significant occurrences have been described by Kauffman (1986, p. 119-121). Trace fossils (the tracks, trails, and burrows of organisms) are very abundant in all the marine units (Dakota through the Niobrara formations), but in most cases these are common fossils. Vertebrate tracks are rare in the PCMS, though one locality in the upper transition units of the Dakota (Locality Kd SC 1) contains a poorly preserved track way. The highly significant Picketwire Track Site occurs adjacent to the PCMS in the upper limestone beds of the middle Morrison Formation. However, large flat outcrops exposing large areas of the tops of these limestones do not occur in the Maneuver PCMS. Plant fossils abound in the Pajarito Shale, but this is characteristic of the Pajarito in New Mexico (Kues and Lucas 1987). The fossil logs at the base of the Bell Ranch Formation are the most significant fossils described in this study, for no other fossilized wood is known from this interval in the western United States. The other stratigraphic units in the area have few or no fossils and are of low paleontologic significance. The following discussion will discuss the stratigraphic units of high, moderate, and low paleontologic significance.

Table 2. Fossils Known from the Stratigraphic Units Exposed in and Adjacent to the Pinon Canyon Maneuver Site.

		Quaternary Alluvium	Niobrara: Smoky Hill Member	Niobrara: Fort Hays Member	Carlile Shale	Greenhorn Formation	Graneros Shale	Dakota Group: upper transitional units	Dakota Group: Pajarito Formation	Dakota Group: Mesa Rica Sandstone	Dakota Group: Glencairn Formation	Dakota Group: Lytle Formation	Morrison: upper	Morrison: middle	Morrison: lower	Bell Ranch Formation	Entrada Sandstone	upper Dockum Group
Marine	Marine Reptiles						X											
	Marine Fish			X	X		X											
	Shark Teeth			X	X	X	X											
	Ammonites		X	X	X	X	X											
	Oysters		X	X	X	X	X											
	Marine Clams		X	X	X	X	X				X							
	Marine Snails			X	X	X	X											
	Foraminifers		X	X	X	X	X	X			X							
	Trace Fossils		X	X	X	X	X	X	X	X	X	X	X	X				
Terrestrial	Wood							X	X	X		X	X	X		X		
	Leaves								X				X					
	Stromatolites													X				
	Ostracodes													X				
	Dinosaur Tracks							X						X				
	Dinosaurs												X					
	Terrestrial Reptiles															X		
	Freshwater Clams	X												x				
	Freshwater Snails	X																
Paleontologic Significance	high			X	X[1]	X[1]	X[1]						X			X		
	medium	X	X					X	X		X			X				
	low				X[2]	X[2]	X[2]			X		X			X		X	X

[1] limestone members [2] black shales

Stratigraphic Units with High Paleontologic Significance

The stratigraphic unit with the highest paleontologic significance in the PCMS is the Middle Jurassic Bell Ranch Formation. The Bell Ranch is a sequence of multicolored breccias, sandstones, and siltstones that filled a paleovalley sequence cut into the underlying Entrada Sandstone. Near the base of the deepest valleys, the Bell Ranch contains large fossil logs (Figure 12) as large as 1.45 m in diameter and 2.2 m long. The logs are silicified with no internal structure preserved, but they represent ancient gymnosperm trees, probably aracarians or conifers. In the locality with the best preserved logs (96 Pal 3), the *in situ* logs are all nearly horizontal and are preferentially oriented either parallel or perpenticular to the valley trend. The logs at this locality represent an ancient log jam at the base of a deep and narrow valley. The logs and wood in the Bell Ranch are limited to the bottoms of the deepest paleovalleys and so far only two wood localities are known. However, no other Middle Jurassic logs are known from the Western United States, so the Bell Ranch logs at the PCMS are very significant paleontologically. Bones of a turtle and an unidentified vertebrate have been reported

Figure 12. Fossil logs from the Lost Korgel Forest (96 Pal 3). A) A narrow, long fossil log. The length of the rule is 0.35 m. B) a large log, 1.45 m wide.

from the Bell Ranch by Kauffman (1986) but no bones were found during the present study.

The Morrison Formation is also significant paleontologically. The Morrison is the only unit in thePCMS that has numerous vertebrate fossils as well as scattered plant localities. The vertebrate fossils include bones of dinosaurs and gastroliths, highly polished chert and quartz pebbles (Figure 13) that are thought to have been polished in the crops of dinosaurs. All of the *in situ* vertebrate remains found in this study were from the mudstones and sandstones of the upper Morrison. The bones are typically dark gray (Figure 14) but can range from white to light red in color and some are filled with silica cement (Figure 15). They typically occur in conglomerates associated with lenticular sandstones. These conglomerates contain large bone fragments, mudstone rip-up clasts, and chert gravel. One bone locality (Jm OVM 6) has bones within mudstones. No complete bones were found in the area but large bones of sauropods are the most typical remains. The localities with the most abundant and well preserved bones include Jm OVM 1 and Jm OVM 4. Jm OVM 4 contains the only dinosaur tooth and jaw material known from the area (Figure 16). The jaw and tooth are of a diplodocid sauropod (Figure 17). Gastroliths can occur with the fossil bones or are widely scattered in the mudrocks of the upper Morrison. The middle Morrison limestones contain ostracodes, fragments of plant stems, and stromatolites (thin laminated limestones formed by bacterial and algal mats). The stromatolites are restricted to the lower limestones of the middle Morrison. The ostracodes, plant stems, and the dinosaur trackways of the Picketwire Track Site are all in the upper limestones of the middle Morrison. No fossils are known from the lower Morrison gypsum sequence.

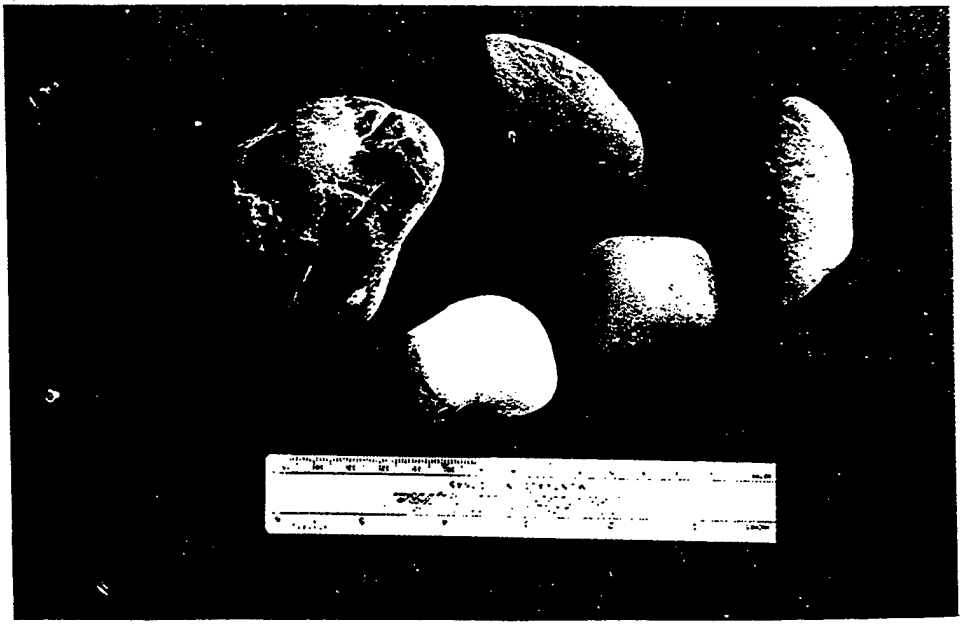

Figure 13. Highly polished gray chert and yellow quartz pebbles found in the mudstones of the upper Morrison Formation. These are interpreted to be gastroliths, or dinosaur crop stones.

Figure 14. Large dinosaur bone fragments from the upper Morrison at Jm OVM 5.

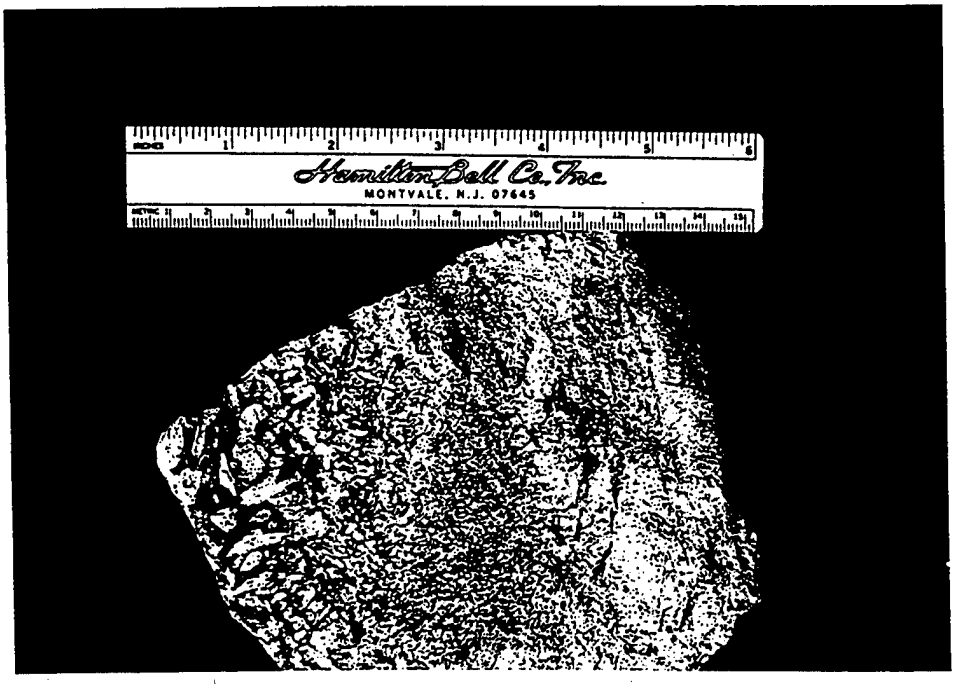

Figure 15. A cross-section view of a large fragment of a dinosaur bone from 96 Pal 1. The dark material on the left side is red chert.

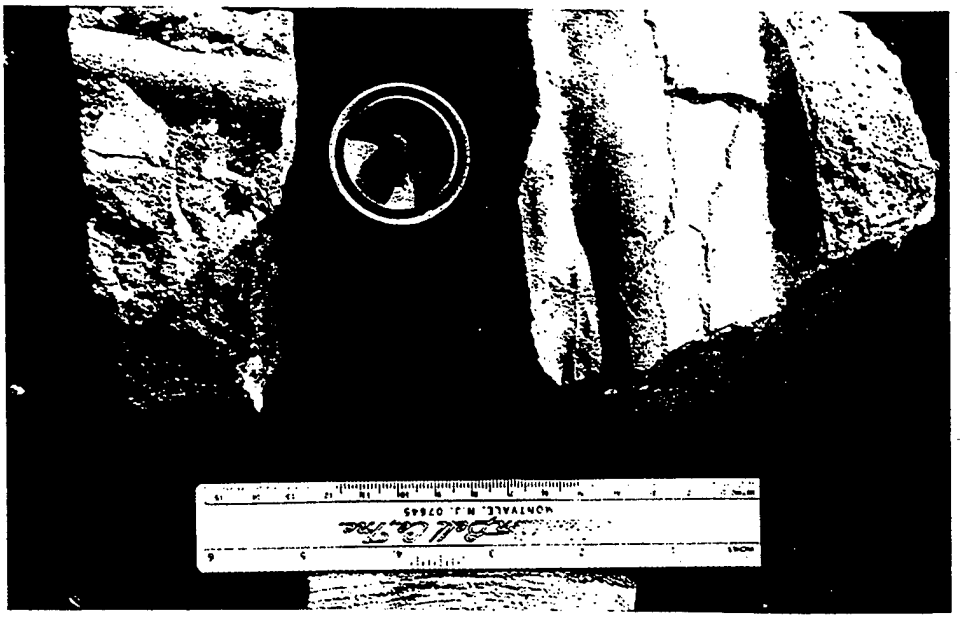

Figure 16. Dinosaur fossils from Jm OVM 4. On the left is a small bone in a slab of conglomerate. The center contains a tooth of a diplodocid sauropod. The fossil on the right is a mold of a portion of a sauropod jaw.

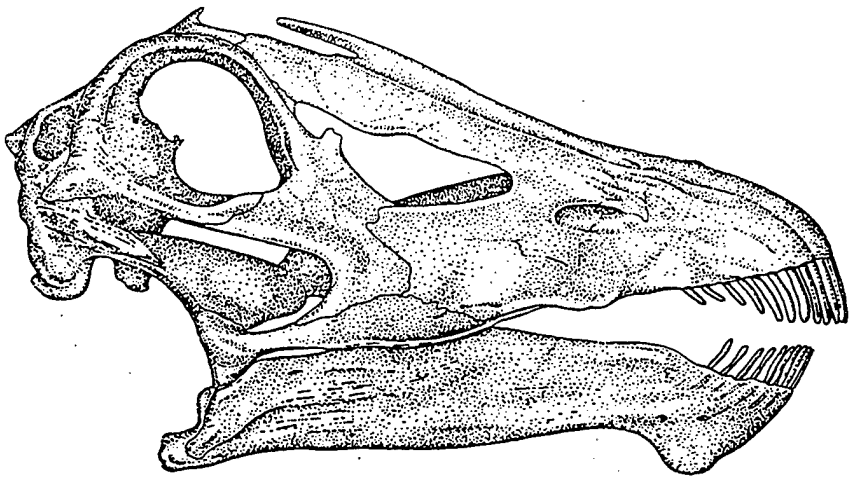

Figure 17. A diagram of a skull of *Diplodocus*. The tooth from Jm OVM 4 is short and is probably from the rear of the tooth row. From Ostrom and Mc Intosh (1966).

The limestones of the marine Cretaceous sequence (the Graneros through Niobrara formations) contain a very abundant (Figure 18) and significant molluscan fauna as documented by Kauffman (1986). The PCMS is very important for understanding Cretaceous invertebrate paleobiogeography and biostratigraphy because many marine mollusk taxa that are found in the area also occur in the Gulf Coast and other continents. These occurrences are well documented in Kauffman (1986), and little is needed to update this information. The location of Kauffman's Greenhorn Locality #22, a very significant locality in the Bridge Creek Limestone Member, was problematic, but has been relocated during this study.

Figure 18. Overlapping shells of the inoceramid clam *Mytiloides* from the Bridge Creek Limestone Member of the Greenhorn Formation at Kauffman's Locality #22.

Stratigraphic Units with Moderate Paleontologic Significance

The Pajarito Formation and the upper transitional units of the upper Dakota Group have abundant plant and trace fossils. Taylor (1974) found identifiable plant fossils from the Pajarito at three localities. These localities and their associated plant taxa are listed in Table 3. Fossil wood is abundant in both Pajarito and the upper transitional units, and this wood typically contains burrows of the shipworm, *Teredo* (Figure 19). Burrows of invertebrates are common in both of these units, and at one locality (Kd SC 1) in the upper transitional units are the undertracks of a bipedal dinosaur. These tracks are represented by alternating staggered small depressions on the top of a thick sandstone slab near the head of Red Rock Canyon. Their indistinct form is a result of the dinosaur walking on a sedimentary surface above the sand bed which now shows the tracks. As the dinosaur walked, it deformed the sediment layers within about a half of a meter of the

Table 3. Fossil Plants from the Pajarito Formation at Pinon Canyon Maneuver Site and Adjacent Areas, from Taylor (1974).

Auracarites sp. (gymnosperm tree)
Sterculia cf. *S. coriacea* Knowlton (angiosperm)
Aralia sp. (angiosperm)
Cyatheites sp. (tree fern)
Onoclea fecunda (Lesquereux) Knowlton (?) (fern)
Sequoia cf. *S. obovata* Knowlton (gymnosperm)

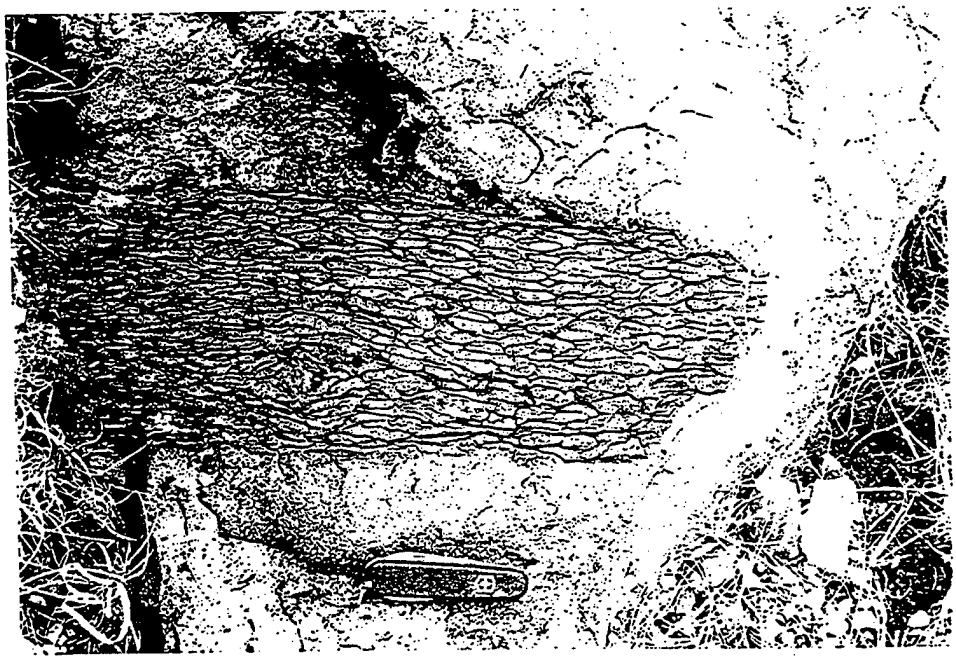

Figure 19. A fragment of fossil wood from the upper transition units of the Dakota Formation on the ridge between Horse and Sugarloaf canyons. The wood has almost been destroyed by the burrows of the shipworm *Teredo*, now represented by the overlapping worm-shaped features.

surface including the sand bed that now preserves the tracks. Therefore, these tracks are called undertracks, and are recognized primarily by their spacing. Plants and traces (including dinosaur tracks) are known from the Pajarito Formation and equivalents of the upper transitional units in New Mexico (Kues and Lucas, 1987). Therefore, the paleontologic significance of these units is considered moderate. Few fossils are known from the lower Dakota formations, but the casts of logs are known from the Lytle Formation and shales containing fish scales are known from the Glencairn Formation (Kauffman 1986). The paleontologic significance of the lower Dakota rocks in the PCMS is lower than that of the fossiliferous upper Dakota rocks, but the the Glencairn Formation can be considered to have moderate paleonotologic significance. Finally, the Smoky Hill Member of the Niobrara Formation exposed in the southwest part of the PCMS contains abundant shells of inoceramid bivalves. These shells are common in the

Smoky Hill of other regions and, until additional studies of the Smoky Hill fauna determines otherwise, the unit is considered to have moderate paleontologic significance.

The Quaternary stream alluvium can contain shells of freshwater mollusks. These are most abundant near the mouth of Taylor Arroyo, and include two species of freshwater clams and one species of freshwater snail (Figure 20). These mollusk indicate the presence of past perennial waters. The Quaternary alluvium in the lower part of Taylor Arroyo has a moderate paleontologic significance.

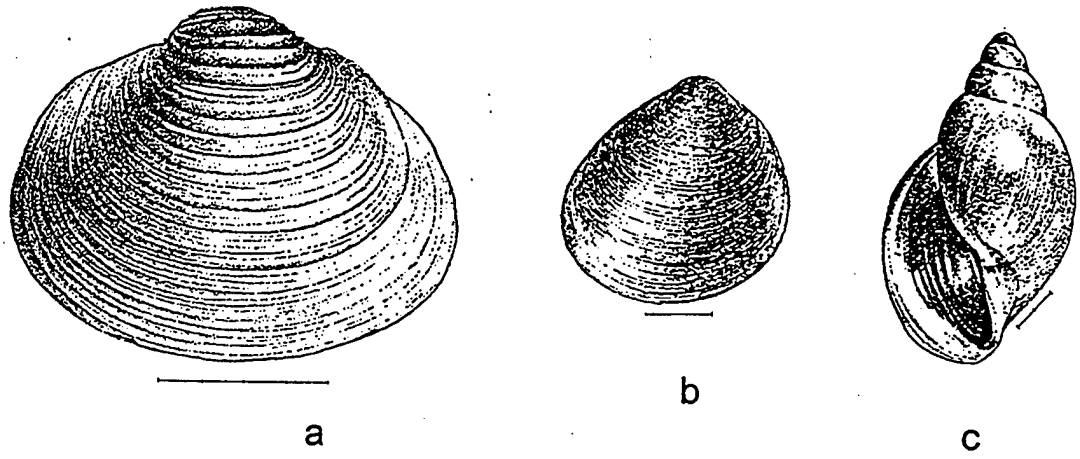

Figure 20. The shells of a) *Sphaerium striatinum*, the striated fingernail clam; b) *Pisidium compressum*, a freshwater seed clam; and c) *Physella virgata*, a freshwater snail that occur in the Quaternary alluvium at the mouth of Taylor Arroyo. The diagrams are from Burch (1975, 1980), and the small bars are divided into millimeters.

Stratigraphic Units with Little or No Paleontologic Significance

Few fossils have been found in the black shales of the Graneros, Greenhorn, and Carlile formations, and these have been primarily ammonites associated with carbonate nodules (Kauffman 1986). The Mesa Rica Sandstone of the upper Dakota Group contains few fossils, including only trace fossils and scattered wood fragments (Kauffman 1986). The Lytle Formation contains trace fossils and rare casts of logs (Kauffman 1986). These units have low paleontologic significance.

No fossils are known from the Entrada Sandstone and the upper Dockum rocks in the PCMS. The Quaternary older gravels, eolian sand deposits, and the undifferentiated Quaternary deposits are not known to have fossils. Finally, the shallow intrusive dike of the Hogback was implaced below the ground surface and has no fossils. Fossils can occur in the landslide deposits but these represent a jumbled assemblage derived from the upper Morrison and Dakota Group. All of these rock units have essentially no paleontologic significance.

Management Recommendations

Of the 12 localities newly documented in this study (not including Kauffman's Locality 22), only four localities are considered to be significant. These localities include the Lost Korgel Forest (96 Pal 3), the Red Rock Wood Locality (Jb OVM 1), Sandy Swift's Bone Bed (Jm OVM 4), and Bill Hughes' Sauropod Locality (Jm OVM 1). The two fossil wood localities in the Bell Ranch Formation are significant because they are the only known localities of Middle Jurassic wood in the western United States. The two dinosaur localities have the greatest accumulations of bones of any Morrison localities in the area. The other eight localities have enough significance to be documented, but are not as important paleontologically.

Several recommendations concerning the management of these fossil localities are as follows. All future construction plans should include a consideration of the possible disturbance to any of the 12 localities, and such disturbance should be minimized. The four significant localities should be periodically examined for any new significant fossil materials that may be exposed and monitored to determine the effects of human disturbance. The other eight localities, especially the dinosaur localities, should be examined only after major human activities have occurred in their vicinity. Future researchers in the area should also be vigilant for new fossil localities and any new localities should be adequately documented. If any significant new fossil materials should be collected, then this material should be prepared and curated into a long-term research collection. No materials should be collected if they cannot be entered into a managed collection.

Suggestions for Future Research

Four major projects involving future research on the paleontology and geology in the PCMS have become apparent from the current study. The first possible project is to determine the origin and distribution of the Bell Ranch Formation. This would involve determining the relations between the Bell Ranch Formation and the underlying Entrada Sandstone, determine the taxonomic affinities of the fossil wood, and attempt to find additional wood and vertebrate localities. This proposed study would include all the outcrops in Red Rock, Welsh, and Bravo canyons and the southern tributaries to Bent Canyon. This project is very important because of the unique Middle Jurassic fossils of the Bell Ranch.

A detailed study of the stratigraphy and origin of the Morrison Formation in the PCMS would provide an important stratigraphic and sedimentologic framework for the various fossil localities. An especially interesting subproject would be to study the changes in the lacustrine environments of the limestone beds of the middle Morrison. This would also include an attempt to identify the fossil plants in the upper limestones.

A study of the plant fossils of the Pajarito Formation may provide important information concerning the diversity, paleoecology, and evolutionary development of the early angiosperms. A paleobotanist could recollect the localities listed by Taylor (1974) and would have numerous opportunities to find additional localities. A detailed sedimentologic and stratigraphic study of the Pajarito Formation and the upper

transitional units would also provide important information concerning the transition from terrestrial to marine conditions.

The final potential study is to map the various members of the Cretaceous marine rocks above the Dakota Group. This would help clarify the locations of the most fossiliferous outcrops, and provide data on the distribution of structures in the PCMS. Detailed mapping is also needed of the Hogback dike, and the older "Pitty gravels." The end result of this work would be a detailed field-checked geologic map of the PCMS.

Comments on the Present Status of Geologic Mapping

The geologic maps supplied by this study include information derived from the fieldwork. This information includes the distribution of fossil localities not included in the preliminary mapping, and the distribution of stratigraphic units better reflecting the actual stratigraphy of the area. The contacts were plotted on the maps using the aerial photos listed in Evanoff (1997). For the most part, the Entrada and Bell Ranch formations were not separated, for the details of this irregular contact cannot be easily seen on the aerial photographs and would involve more field time than this study allowed. Likewise the formations of the Dakota Group were not separated because the contacts are typically covered by debris. The base of the cliff of the Mesa Rica Sandstone was used to separate the lower and upper Dakota units. The new mapping also shows less Quaternary deposits. The long fingers of Quaternary alluvium in the bases of most of the small canyons shown in the older maps have been eliminated in the new maps, for alluvium is a minor consituent of these valley bottoms. Much of the Dakota and upper Morrison is covered by debris which is not shown on these new maps, except for the distribution of large landslides that were identified in the field or are very obvious in the aerial photographs. The edge of mapping mostly coincides with the contacts of the upper Dakota with the undifferentiated Quaternary deposits as mapped in the previous project (Evanoff, 1997). Figure 21 is an explanation of the current maps and the symbols used in the stratigraphic columns (Figures 2 and 4).

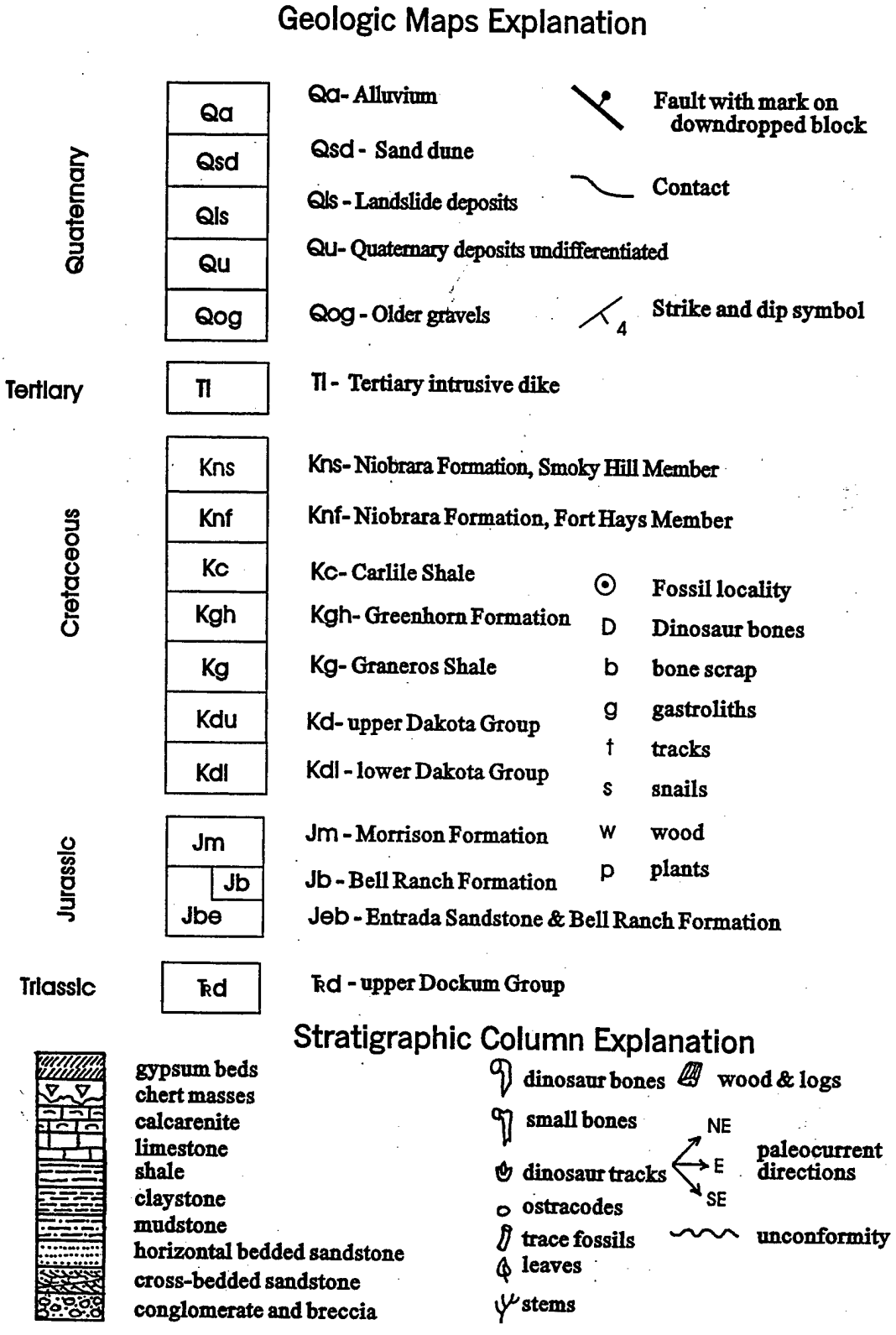

Figure 21. Explanation of symbols for the geologic maps and the stratigraphic columns of the Pinon Canyon Maneuver Site.

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